PROJECT NO.:

TITLE: Maturity and Storage Impacts on Apple Volatile Production

YEAR INITIATED: 1997 **CURRENT YEAR:** 1999-2000
TERMINATING YEAR: 1999-2000

PERSONNEL: James Mattheis, Plant Physiologist,
USDA, ARS, Wenatchee, WA
John Fellman, Associate Professor
DHLA, WSU, Pullman, WA

JUSTIFICATION:

Volatile compounds produced by fruit are an essential component of flavor and fruit quality. The synthesis of flavor volatiles is dependent on several factors including fruit maturity, variety, storage conditions and duration of storage. Maturity at harvest determines how fruit respond to controlled atmosphere (CA) storage conditions. Extended storage in low oxygen/high carbon dioxide atmospheres suppresses formation of volatile compounds, the degree of suppression depending on O_2/CO_2 concentrations and duration of storage.

Increased competition in the mid- and late-season CA marketplace from southern hemisphere fresh apples has provided consumers with alternatives to Washington CA fruit. These market forces indicate Washington apples must be of highest quality to retain their competitive advantage. Identifying optimal fruit maturity at harvest and CA conditions that promote retention of fruit quality (firmness, titratable acidity, soluble solids content, etc.) as well as synthesis of flavor compounds after storage would aid Washington producers marketing CA fruit. Additional research exploring the biochemistry of apple flavor is being conducted by Dr. Fellman at Washington State University.

OBJECTIVES:

1. Determine how CA storage regimes impact the capacity of apples to produce flavor volatiles after removal from storage. This includes evaluation of novel CA regimes in which gas concentrations are manipulated during storage.

2. Develop protocols to enhance apple aroma by addition of naturally occurring volatile compounds.

3. Evaluate impacts of exogenous compounds that manipulate apple fruit ripening (methyl jasmonate, 1-methylcyclopropene) on volatile production.

4. Develop CA storage regimes for watercored Fuji apples that minimize internal browning.

Progress:

Volatile production and fruit quality following gamma irradiation of Gala apples.

Gala apple fruit treated with 0.5 $\mu l \cdot L^{-1}$ 1-methylcyclopropene (MCP) or air (non-MCP) for 12 h at 68 °F were exposed to gamma radiation at doses of 0, 0.44, 0.88, or 1.32 kGy at 73 °F, and then stored at 68 °F. Production of volatile compounds was measured on the day of irradiation and 1, 3, 7, 14 and 21 days after irradiation. Both MCP treatment and irradiation significantly inhibited ethylene production. MCP treatment significantly reduced production of volatile esters and alcohols, while irradiation inhibited production of most but not all esters and some alcohols by non-MCP treated fruit. The inhibition of volatile production following irradiation increased with dose. Only the non-MCP treated fruit irradiated at 0.44 kGy began to produce esters during the 21 day period following irradiation, and the ester production rate in these fruit was comparable to that of the non-irradiated fruit 21 days after irradiation. Production of methyl and propyl esters was inhibited more than other esters following irradiation or MCP treatment. The impact of irradiation on production of esters and alcohols by MCP treated fruit was minimal. The results indicate both MCP and ionizing irradiation inhibit production of many aroma compounds produced by ripening apple fruit.

Irradiation impacts on fruit quality were dependent on whether fruit had been previously been treated with MCP. Without MCP, irradiation did not result in significant quality differences when fruit were stored 8 weeks at 32 ^{o}F after treatment. Some fruit irradiated with 1.32 kGy developed internal browning in the mesocarp tissue near the peel. When stored at 68 ^{o}F after irradiation, development of internal browning increased with dose. Fruit treated with MCP prior to irradiation were firmer and had higher titratable acidity (TA) compared to non-MCP treated fruit 8 weeks after treatment, however, TA decreased with increased irradiation dose. Treatment with MCP did not prevent development of internal browning in fruit stored at 68 ^{o}F following irradiation.

Gala apples previously stored in CA for 6 months were used to evaluate the use of DPA for reduction of irradiation-induced internal browning. Apples were treated with 2000 ppm DPA then irradiated the following day at 0.88 kGy. All irraditated fruit were injured and developed extensive internal and external browning. Pre-irradiation treatment with DPA did not reduce injury development. The irradiation treatment also resulted in significant loss of firmness and TA.

Response of Fuji apples to delayed CA

Fuji apples harvested from a commercial orchard near Orondo were used to evaluate several protocols for efficacy to reduce development of CO_2 injury during CA storage. Treatments included CA established within 3 days of harvest, 2 to 6 week delay in CA establishment after harvest, 1 to 3 month delay in accumulation of CO_2 during CA, and all of these treatments preceded by MCP treatment. This experiment will be concluded in June and results will be presented at the WTFRC Postharvest Review in July.

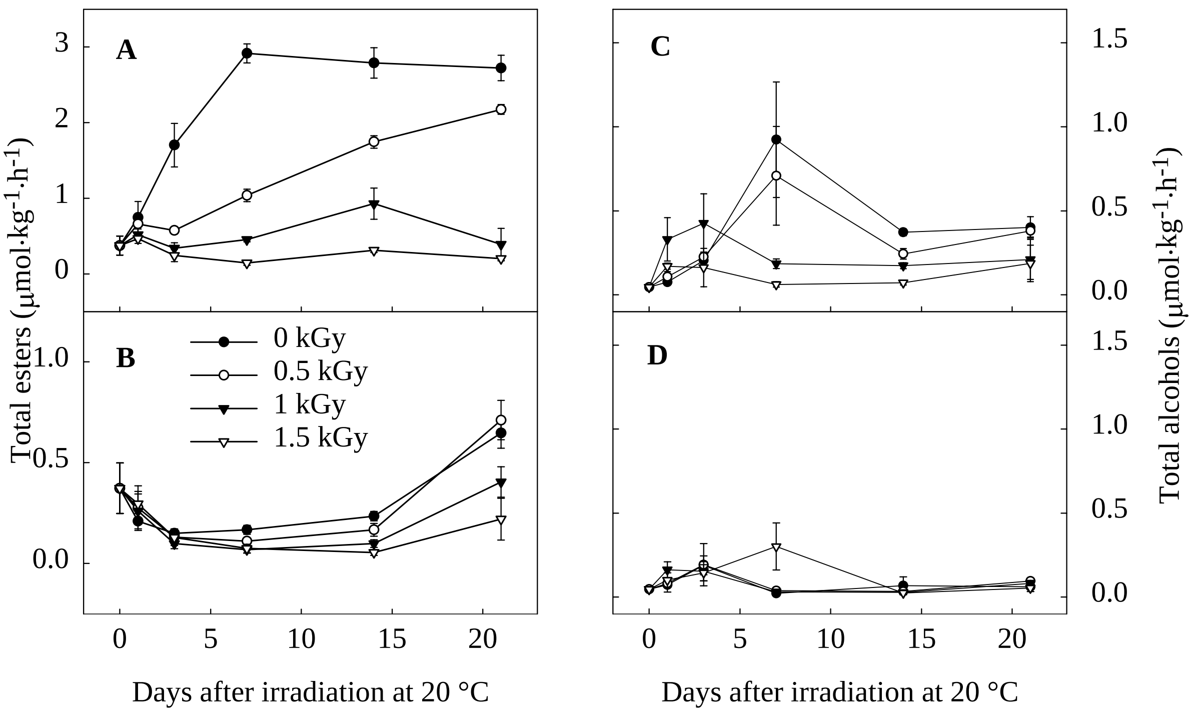

Figure 1. Ester (A, B) and alcohol (C, D) production by 'Gala' apples. The fruit treated with (B, D) and without (A, C) 0.5 $\mu L \cdot L^{-1}$ MCP were exposed to 0, 0.44, 0.88 or 1.32 kGy gamma irradiation, then stored at 68 °C. Vertical bars represent standard deviation.

Volatile production by Gala apples following treatment with MCP and/or CA storage

Gala apples harvested at the WSU-USDA Columbia View orchard were used to compare volatile production following MCP treatment and/or CA storage. Fruit were treated with MCP at 0.01, 0.1, 1 or 10 ppm, then stored in air or CA. Two CA regimes were used, 1 or 2 % O_2 with 2% CO_2. Quality of fruit continually exposed to ethylene during CA storage was also evaluated. Volatile production of Gala apples in response to these treatments was characterized and results will be presented at the research review.

As the reduction in volatile production occurs slowly during CA but rapidly after MCP treatment, several storage protocols using both CA and MCP were evaluated. These included CA storage for 2 or 4 months prior to MCP treatment, and also MCP treatment, air storage for 4 months, then CA storage. Volatile production of Gala apples in response to these treatments was characterized and results will be presented at the research review.

Summary of Results, 1997-2000

Volatile compounds produced during apple fruit ripening are responsible in part for apple fruit aroma and flavor. Many factors influence the production of these compounds including fruit maturity at harvest, storage conditions and storage duration. Ethylene is required for volatile production, therefore practices that reduce fruit exposure to ethylene or ethylene action can result in reduced volatile production.

Apple storage in CA can result in reduced fruit volatile production upon return to air storage. The extent to which volatile production is reduced depends on atmosphere, particularly the use of very low O_2 concentrations. As continuous exposure to low O_2 results in reduced production, a series of experiments was conducted to evaluate fruit response to brief exposures to ambient O_2 during CA storage. While periodic exposure to air improves post-storage volatile production without loss of firmness or titratable acidity, the increase in volatile production is unlikely to result in enhanced consumer acceptance. The addition of ethylene to the air portion of the CA cycle also results in enhanced volatile production, however, firmness and titratable acidity loss also increase using this treatment. The interest and use of high CO_2 storage conditions can also impact post-storage volatile production. While Gala apples are not particularly sensitive to CO_2 -induced internal breakdown, volatile production decreases as CO_2 increases during storage. This response is most evident when storage O_2 concentrations are greater than 1%.

Many volatiles produced by apples are simple esters that are synthesized continuously during ripening. These compounds diffuse out of the fruit after production, therefore factors that reduce volatile synthesis result in fruit with less aroma. The volatile nature of these compounds and the tendency of apple fruit to absorb volatile materials allows mixtures of these compounds added to storage rooms to diffuse into the fruit. Knowing which compounds are most important for aroma of a particular cultivar is critical to development of strategies to enhance aroma. For Gala apples, this information was obtained through research conducted by Anne Plotto and Mina McDaniel. By selecting compounds based on cultivar and adjusting the amounts of each compound in the mixture, apples with enhanced aroma and flavor can be produced. The most common aroma compounds produced by apples are easy to obtain as food-grade materials, and treatments can be conducted while fruit is in storage. While prolonged (2-4 months) exposure can result in peel phytotoxicity in some cultivars, Granny Smith in particular, aroma enhancement at concentrations that improve flavor do not result in degradation of other quality attributes including firmness and titratable acidity. Tests conducted in our laboratory as well as at the Stemilt Research facility indicate sufficient ester accumulation occurs in Gala and Delicious apples to be detectable by untrained consumer panels for several weeks following treatment. Based on the current prices for these compounds, this treatment represents a potential low cost means to enhance apple flavor.

Volatile production following treatment with 1-methylcyclopropene (MCP)

The ethylene action inhibitor MCP is an effective tool to slow the rate of apple fruit ripening. MCP treatment of apple fruit slows loss of firmness, titratable acidity and prevents development of several physiological disorders. The use of MCP also results in reduced volatile production. While the reduction in volatile production following MCP treatment occurs faster than that induced by CA storage, volatile production resumes after a period of storage following treatment. The duration of reduced volatile production increases with MCP treatment concentration within the range from 0.1 to 1 ppm, and is also dependent on whether MCP-treated fruit are subsequently stored in air or CA. Although volatile production by MCP-treated fruit increases over time, increased production is accompanied by greater firmness and titratable acidity loss compared to apples stored in CA without MCP treatment. For cultivars other than Gala, reduced volatile production may be an acceptable tradeoff for prolonged retention of firmness, titratable acidity and prevention of physiological disorders.

Development of internal breakdown in Fuji apples during CA storage continues to occur in Washington state warehouses. Research conducted in our laboratory over the past 3 years has identified a number of factors that contribute to development of this injury. The injury is induced by CO_2 and fruit susceptibility increases with advanced maturity and the presence of watercore. While the risk of injury increases with the use of CO_2 at concentrations above 1% in CA, injury can also occur at 1% if CA is imposed soon after harvest. Delaying establishment of CA greatly reduces the risk of injury without significantly reducing fruit quality after long-term storage. Unlike other cultivars that benefit from rapid CA, Fuji benefits from prompt cooling followed by a period of air storage prior to CA. Our results indicate a significant reduction in CO_2 injury by delaying CA establishment for 2 weeks after harvest. Delaying accumulation of CO_2 in the CA room is another strategy to reduce development of injury. Imposition of low O_2 conditions while keeping CO_2 below 0.5% for 1 to 3 months after harvest reduces development of injury and still results reduced fruit quality loss compared to fruit stored in air.

Although both delayed CA or delayed CO_2 accumulation in CA reduce development of CO_2 injury, the use of DPA prior to storage is the most effective treatment for prevention of these disorders. Residue analyses of apples indicate DPA is mobile into the fruit and is present in tissues in which CO_2 injury typically develops. The use of DPA applied as a recirculating drench can increase the risk of fruit decay via inoculation of harvest wounds, however, when fruit are harvested at optimum maturity or late harvest fruit is not stored for extended periods, the risk of decay is reduced. When used according to the label, DPA presents a viable option for reducing CO_2 injury during CA storage as well as providing protection from development of superficial scald.

The termination of this project coincides with expansion of my laboratory's research with MCP. Over the past two years our work with MCP has begun to overlap into the objectives of this project. Rather than continue with two separate projects, I propose to combine them into one larger project that more accurately reflects the work ongoing in my laboratory. Several of the areas of research covered in this project, including volatile production in response to storage conditions, aroma enhancement and reduction of CO_2 injury will continue to be addressed. Characterization of volatile production is a standard part of the measures of fruit quality we conduct to evaluate apple response to storage treatments. We will continue to be active in this area of research, and the use of MCP provides another tool with which to explore the mechanisms by which apple volatile production is regulated.

PUBLICATIONS:

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